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Distance Measurement Based on Pixel Variation of CCD Images

Chen-Chien Hsu
Department of Electronic Engineering
Tamkang University
Taipei County, Taiwan
jameshsu@mail.tku.edu.tw

Ming-Chih Lu
Department of Electronic Engineering
St. John's University,
Taipei County, Taiwan
l3210m@mail.sju.edu.tw

Ke-Wei Chin
Department of Electrical Engineering
Tamkang University
Taipei County, Taiwan
stanleychin@livemail.tw

Abstract —**This paper presents a distance measurement method based on pixel number variation of images for digital cameras by referencing to two arbitrarily designated points in image frames. Based on an established relationship between the displacement of the camera movement along the photographing direction and the difference in pixel counts between reference points in the images, distance from an object can be calculated via the proposed method. To integrate the measuring functions into digital cameras, circuit design implementing the proposed measuring system in selecting reference points, measuring distance, and displaying measurement results on CCD panel of the digital camera is proposed in this paper. In comparison to pattern recognition or image analysis methods, the proposed measuring approach is simple and straightforward for practical implementation into digital cameras. Experiment results have demonstrated that the proposed method is capable of yielding satisfactory measurement results in a very responsive way.**

Index Terms* —*digital cameras, distance measurement, CCD images, image-based measuring systems, pixels, video signal.

I. INTRODUCTION

As far as noncontact distance measurement is concerned, ultrasonic-based [1]-[4] and laser-based [5]-[11] techniques are among the most commonly-used methods. Unfortunately, measurement accuracy via the laser- and ultrasonic-based methods heavily depended on surface reflectivity of the object under measurement. If the reflection surface is undesired, the measuring system generally performed poorly or not at all. These methods also have difficulties in recording images of the objects while measuring distance. Alternatively, imaged-based methods have been proposed for distance measurement by using CCD (digital camera) [12]-[15]. These methods, however, generally required two cameras set up at different positions to capture two different pictures for further analysis. As a result, pattern recognition or image analysis of a whole image frame were required [16]-[17] to extract features from the images for obtaining the distance measurement. Thus , huge amount of storage capacity and high-speed DSP processors are required for system so established, inevitably resulting in disadvantages in terms of system complexity, processing speed, and establishment cost. As a result, performance of real-time measurement via the pattern recognition or image analysis methods was generally not satisfactory because of the speed constraint. Based on a triangular relationship, an image-based distance measuring system (IBDMS) [18]-[22], [29] was proposed to measure distance and area using two laser projectors and a CCD camera. Unfortunately, the two laser projectors needed to be precisely aligned with the camera, which inevitably imposed a critical constraint on the calibration of the measuring system. Furthermore, measurement accuracy of the IBDMS depended on the distance between the laser projectors. Incorporation of the measuring system into a digital camera might become cumbersome if higher measuring resolution is required [29]. Because of the problems and difficulties via the above-mentioned methods, accurate and reliable measurements were not always guaranteed in real-world applications.

To overcome the problems and difficulties encountered via the existing image-based distance measuring methods, this paper presents a distance measurement method based on pixel number variation in images for digital cameras by referencing to two arbitrarily designated points in the image frames, rather than the laser-projected spots in the image. It is apparent that the actual distance between the reference points will not change no matter the digital camera moves backward or forward along the photographing direction. However, objects in the image frame captured by the camera do vary in size if the camera moves backward or forward along the photographing direction. That is, pixel counts between the reference points in images will be different if the digital camera moves along the photographing direction. By establishing a relationship between the displacement of the camera movement and the difference in pixel counts between the reference points in the images at different photographing distances, we can measure the distance of a remote object. One of the advantages in using the proposed measuring approach is that precise distance between the reference points is not required. Two arbitrarily selected points on the CCD panel covered by the view angle of the camera can be adopted as the reference points in achieving a reliable measurement.

The rest of the paper is organized as follows. Section 2 introduces the proposed measurement method based on variation of pixel counts of CCD images. Determination of an intrinsic parameter for CCD cameras is given in Section 3 to obtain an accurate measurement. Circuit design incorporating the proposed measuring method into a digital camera based on pixel variation of CCD images is given in Section 4. Experiment results of practical measurement are demonstrated in Section 5. Conclusions are drawn in Section 6.

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II. Measurement Based on Variation of Pixel Counts of CCD Images

To equip digital cameras with the function of measuring distance while recording images, performance of the existing IBDMS needs to be improved from two aspects. The first one is to remove the constraint on generating two laser beams precisely formed in parallel. The second one is the determination of an intrinsic parameter for various kinds of CCD cameras so as to achieve an accurate measurement.

A. Relationship between distance and variation of pixel counts

There exists a close relationship between distance and pixel counts (scanning time) on a scan line of an image frame, as revealed in previous researches [18]-[20]. Fig. 1 shows a schematic diagram of a CCD camera capturing images at different photographing distances h_1 and h_2, in which the distance between the optical origin (OP) and the front end of the CCD camera is h_s, $D(h_1)$ and $D(h_2)$ are the real-world maximal horizontal distances formed by the field of view of the CCD camera at photographing distance h_1 and h_2, respectively, ℓ is the actual distance between reference points P_a and P_b, $N(h_1)$ and $N(h_2)$ are the pixel counts of ℓ at photographing distance h_1 and h_2, respectively, and $N_{\max}$ is the maximal pixel number in a horizontal scan line of an image frame, which is fixed and known as a priori irrelevant of photographing distances.

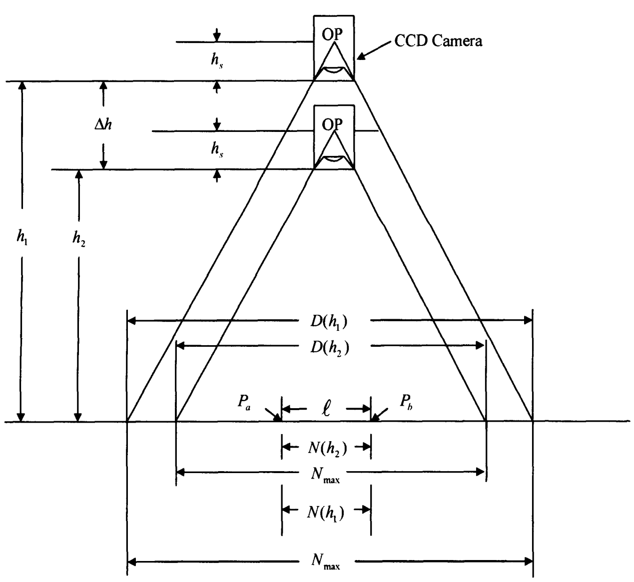


Fig. 1. Schematic diagram depicting the relationship between distance and variation of pixel counts at different photographing distances.

With reference to Fig. 1, we have the following relationship between pixel counts and distances:

$$\frac{\ell}{N(h_1)} = \frac{D(h_1)}{N_{\max}} \tag{1}$$

$$\frac{\ell}{N(h_2)} = \frac{D(h_2)}{N_{\max}}. \tag{2}$$

From (1) and (2), we have:

$$\frac{D(h_1)}{D(h_2)} = \frac{N(h_2)}{N(h_1)} \tag{3}$$

Because of the displacement, $\Delta h = h_1 - h_2$, resulted from the movement of the camera along the photographing direction, two similar isosceles triangles having bases $D(h_1)$ and $D(h_2)$, respectively, are formed as shown in Fig. 1. We have:

$$\frac{N(h_2)}{N(h_1)} = \frac{D(h_1)}{D(h_2)} = \frac{h_1 + h_s}{h_2 + h_s} \tag{4}$$

Substituting $h_1 = h_2 + \Delta h$ into (4), photographing distances h_1 and h_2 can be obtained as:

$$h_1 = \frac{N(h_2)}{N(h_2) - N(h_1)} \times \Delta h - h_s \tag{5}$$

$$h_2 = \frac{N(h_1)}{N(h_2) - N(h_1)} \times \Delta h - h_s. \tag{6}$$

Note that Δh in (5) and (6) is the displacement along the photographing direction due to the movement of the camera. For practical implementation of the proposed measuring system, Δh can be fixed and is known as a priori. As long as h_s becomes available, we can calculate the photographing distance via (5) or (6).

B. Selection of reference points

Fig. 2 shows schematic diagrams illustrating that the variation of image size of an identical object in image frames depends on the photographing distance. When the CCD camera moves forward or backward along the photographing direction, pixel counts between the two reference points in the image frames will be different. On the basis of the variation of the pixel counts between reference points in CCD images, we can derive the photographing distance.

Assume that two arbitrarily selected points P_a and P_b of an object in the image frame are chosen as the reference points. When taking pictures at photographing distance h_2, pixel counts $N(h_2)$ between the reference points $P_a(h_2)$ and $P_b(h_2)$ can be calculated by $N(h_2) = M_R(h_2) - M_L(h_2)$, by adjusting a left and right cursor line on the CCD via a cursor line generation circuit incorporated into the digital camera. Pixel counts $N(h_1)$ at photographing distance h_1 can be obtained in exactly the same way and therefore will not be re-iterated. When the camera is set to the function to measure distance, a highlighted horizontal line on the kth scan line perpendicular to these two vertical cursor lines is generated for easier identification of the reference points. As long as the displacement between the photographing distances,

$\Delta h = h_2 - h_1$, becomes available, we can calculate the distances h_1 and h_2 based on the variation of pixel counts $\Delta N = N(h_2) - N(h_1)$.

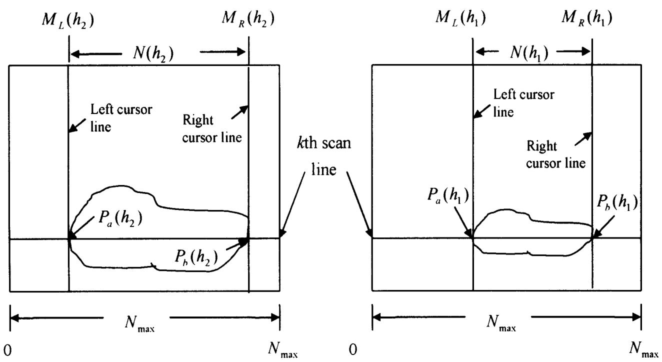


Fig. 2. Schematic diagram showing the variation of image size of an identical object in image frames at different photographing distance h_1 and h_2, respectively.

III. Determination of the Optical Origin for CCD Cameras

To construct a measuring system suitable for all kinds of CCD cameras, the distance h_s between the optical origin (OP) and the front end of the camera needs to be established. Fig. 3 shows a proposed method for obtaining an accurate h_s for a specific CCD camera, in which a muzzle limiting the view angle of $2\theta_s$ is mounted on the CCD camera.

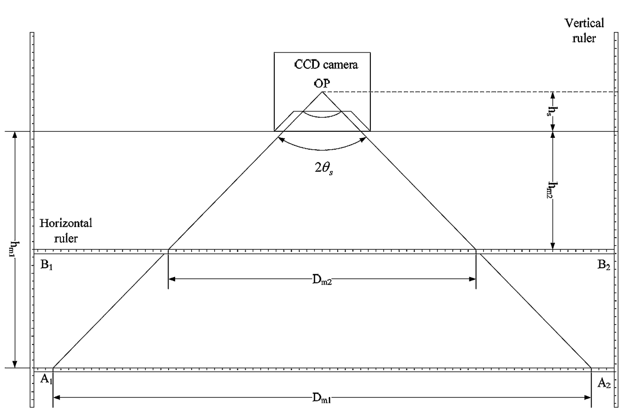


Fig. 3. Mechanism for obtaining an accurate h_s for a CCD camera.

With reference to Fig. 3, when the horizontal ruler is positioned at (A_1 , A_2) and (B_1 , B_2), the distances between the front end of the CCD camera and (A_1 , A_2) and (B_1 , B_2) are h_{m1} and h_{m2} , respectively. By a triangular relationship, we have:

$$h_s + h_{m2} = \frac{1}{2} D_{m2} \cot\theta_s \qquad (7)$$

$$h_s + h_{m1} = \frac{1}{2} D_{m1} \cot\theta_s \qquad (8)$$

Subtracting (7) from (8), we obtain:

$$h_{m1} - h_{m2} = \frac{1}{2}(D_{m1} - D_{m2})\cot\theta_s$$

$$\cot\theta_s = \frac{2(h_{m1} - h_{m2})}{D_{m1} - D_{m2}} \qquad (9)$$

Alternatively, we can obtain:

$$\frac{h_s + h_{m2}}{h_s + h_{m1}} = \frac{D_{m2}}{D_{m1}}$$

by dividing (7) by (8). Thus, the intrinsic parameter of the distance between the optical origin and front end of the CCD camera for any digital cameras can be obtained as:

$$h_s = \frac{h_{m1}D_{m2} - h_{m2}D_{m1}}{D_{m1} - D_{m2}} \qquad (10)$$

IV. Hardware Realization of the Proposed Distance Measuring System

To obtain the distances h_1 and h_2, images captured by the camera at photographing distances h_1 and h_2 can be stored in a memory card for off-line processing by a computer. $N(h_1)$ and $N(h_2)$ are then calculated via image processing software based on the selected reference points P_a and P_b . This approach, however, is very inconvenient for practical implementation. In this paper, we will propose a hardware design for incorporation into a digital camera to measure distance and display measured results on CCD panel of the digital camera in addition to full camera functionalities.

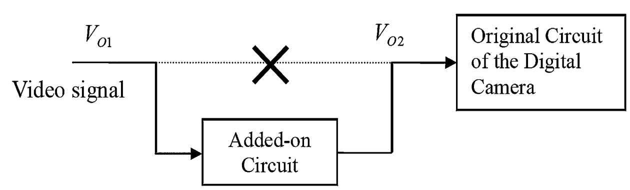


Fig. 4. Block diagram depicting the hardware design incorporated into a digital camera to measure and display distance.

Fig. 4 shows the functional block of an added-on circuit for incorporation into a digital camera to measure and display distance. The original video signal V_{o1} is disconnected from the camera and fed into the added-on circuit implementing the proposed measuring system for generating the cursor lines on the CCD panel of the digital camera and calculating the distance under measurement. Thanks to the added-on circuit, extra functions are provided for measuring distance without making changes to the original processing circuits of the digital camera. As a result, measurement results merged into the video image can be simultaneously displayed on the CCD panel of the digital camera and stored in a memory card together with the video image. Original functionalities of the digital camera are not affected.

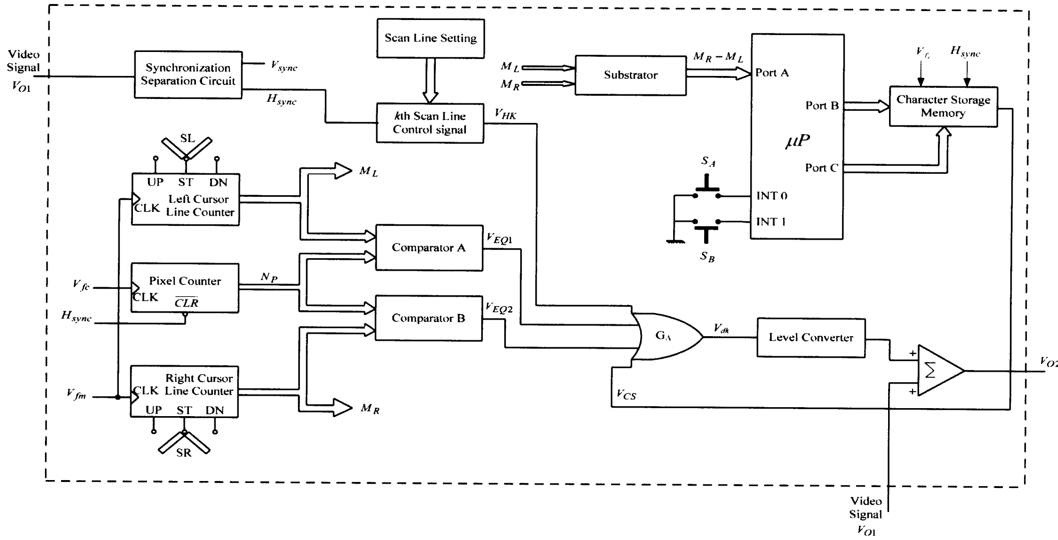


Fig. 5. Schematic diagram of the added-on circuit for incorporation into a digital camera to measure and display distance.

Fig. 5 shows a schematic diagram of the added-on circuit implementing the proposed measuring system in generating the left and right cursor lines on the CCD panel of the digital camera and calculating the distance under measurement. The video signal V_{oI} is processed by a Synchronization Separation Circuit to obtain a horizontal synchronization signal H_{sycn}. With suitable selection on the horizontal synchronization signal H_{sycn} via a Scan Line Setting circuit, a particular scan line, for example, the k_{th} scan line can be chosen to produce a kth scan line control signal V_{HK}. Signal V_{HK} is then fed into a Level Converter via an OR gate G_A to adjust voltage levels to the largest intensity suitable for merging with the original video signal V_{oI}. As a result, a highlighted horizontal line on the kth scan line will be generated on the CCD panel of the camera. Because of the Scan Line Setting circuit, users can arbitrarily designate the kth scan line. Therefore, reference points P_a and P_b can be selected anywhere in the CCD panel by suitably adjusting the control switches SL and SR.

With reference to Fig. 5, V_{fc} is the clock signal for the video signal of the digital camera. As a result, output from the Pixel Counter, $N_p = 0 \sim N_{\max}$, is synchronized with the video signal. The frequency of the input clock to the Left and Right Cursor Line Counters, V_{fm}, is far smaller than V_{fc} to the Pixel Counter. By adjusting switches SL and SR of the Left and Right Cursor Line Counters, clock counts M_L and M_R from the Left and Right Cursor Line Counters can be accurately set in such a way that pressing UP increases the count, pressing DN decreases the count, and pressing ST stops the count, respectively.

Output from the Pixel Counter, N_p, starts counting from 0 in the beginning of every scan line and ends up with $N_P = N_{\max}$. Assume that the Left Cursor Line Counter has a clock count M_L, Right Cursor Line Counter has a clock count M_R, and the Pixel Counter repeatedly scans from 0 to N_{max}. When N_P=M_L and N_P =M_R, outputs from Comparators A and B activate high, i.e., $V_{EQ1} = H_{igh}$ and $V_{EQ2} = H_{igh}$, respectively. That is, output signal from the OR gate G_A, $V_{dk} = H_{igh}$, whenever the Left Cursor Line Counter outputs M_L or Right Cursor Line Counter outputs M_R for all scan lines. The positive pulses V_{dk} after level conversion are added into the original video signal. Therefore, a tiny spot of high intensity is generated on the CCD panel of the digital camera for each scan line at horizontal positions M_L and M_R. The aggregation of the tiny spots for all scan lines at horizontal positions M_L and M_R will then generate two vertical fine lines with highlighted intensity on the CCD panel, perpendicular to the highlighted horizontal line on the kth scan line.

V. Experiment Results

In this section, we present experimental results to demonstrate the effectiveness of the proposed measuring system based on pixel number variation of CCD images.

(A) Experimental set-up and measuring parameters:

(1) CCD camera: Canon A70
(2) Displacement of camera movement : $\Delta h = 30$ cm
(3) Camera parameter: $h_s = 2.5$ cm

(B) Experiment results:

Experiments are conducted adapting to practical situations with the use of digital cameras. Different reference points are chosen depending on photographing ranges under consideration, because broader range is covered when shooting at a longer distance while narrower when shooting at a shorter distance. The rationale is that we choose suitable reference points to allow easier identification of the objects in the image frames.

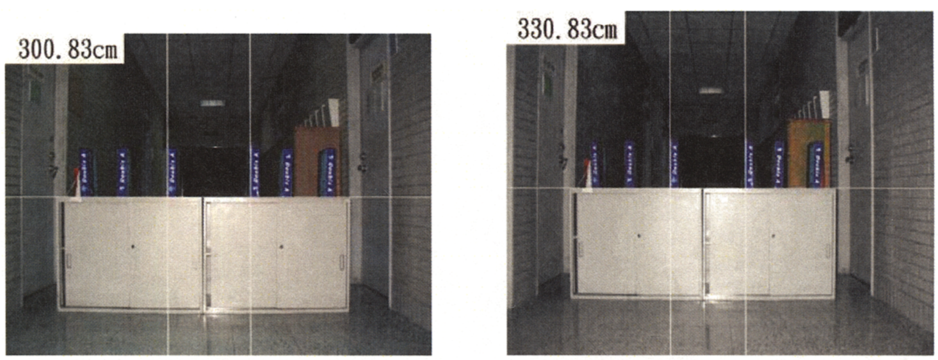
Table I shows measurement results at photographing distances ranging from 1 to 5 meters, where actual distance between reference points, P_a and P_b, is 50 cm. As shown in Table I, the measurement errors at various photographing distances fall within a tolerable range via the proposed method. . As measuring distances increase, suitable reference points, P_a and P_b, need to be selected. Table II shows the measurement results at photographing distances ranging from 2 to 6 meters, with an actual distance of 100 cm between the reference points.

As an evidence to show the effectiveness of the proposed approach, images showing the measured distance of 300 cm and 540 cm on the CCD panel of the digital camera via the proposed method are demonstrated in Figs. 6-7, respectively. As shown in these figures of the experiment results, there is no restriction on the selection of reference points. As long as objects in the image frame can be clearly identified for labeling the reference points P_a and P_b , the proposed approach can easily obtain the measured results.

VI. Conclusions

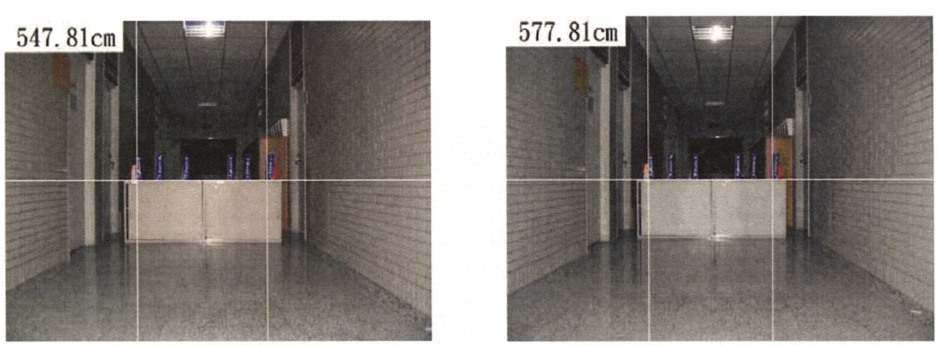
In this paper, a measuring system based on pixel number variation of CCD images is presented, equipping digital cameras with distance measurement functions while recording images. Because of the design of the added-on circuit which generates cursor lines on the CCD panel and calculates the distance under measurement, the proposed method is capable of measuring distance and displaying the measured results simultaneously on the CCD panel without making changes to the original processing circuits of the digital camera. Initial investigation of the proposed method has revealed satisfactory measurement results.

To further reduce the weight and size of the digital camera capable of measuring distance, the hardware circuits can be implemented by FPGA, which is currently under implementation. To fully utilize digital camera to deal with real-world measurement applications, efforts will be made to provide extra functions for incorporation into a single digital camera to measure width and length of a remote object in addition to the distance measurement. As demonstrated in the paper, the proposed measuring system has substantially overcome problems and difficulties encountered in conventional image-based measuring methods and demonstrated itself as a simple yet accurate way in measuring distance while simultaneously recording images for CCD cameras.



$\ell = 50cm, h_2 = 300cm$ $\ell = 50cm, h_1 = 330cm$

Fig. 6. Images showing the measured distance on the CCD panel of the digital camera via the proposed method.



$\ell = 50cm, h_2 = 300cm$ $\ell = 50cm, h_1 = 330cm$

Fig. 7. Images showing the measured distance on the CCD panel of the digital camera via the proposed method.

TABLE I

MEASUREMENT AT PHOTOGRAPHING DISTANCES RANGING FROM 1 TO 5 METERS

Actual distance (h_2)	120cm	180cm	240cm	300cm	360cm	420cm	480cm	540cm
$N(h_2)$	993	667	502	400	334	287	252	225
$N(h_1)$	797	573	447	364	309	268	237	213
Measured distance (cm)	119.49	180.37	241.32	300.83	368.3	420.66	471.5	530
Error%	-0.4	0.2	0.5	0.2	2.3	0.1	-1.7	-1.8

Note: Distance between P_a and P_b is 50 cm.

TABLE II

MEASUREMENT AT PHOTOGRAPHING DISTANCES RANGING FROM 2 TO 6 METERS

Actual distance (h_2)	300cm	360cm	420cm	480cm	540cm	600cm	660cm	720cm
$N(h_2)$	754	632	542	475	423	380	348	318
$N(h_1)$	690	584	506	447	401	362	333	305
Measured distance (cm)	305.56	362.5	419.17	476.43	544.32	600.83	663.5	701.35
Error%	1.8	0.6	-0.1	-0.7	0.7	0.1	0.5	-2.5

Note: Distance between P_a and P_b is 100 cm.

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